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Sustaining America's Aquatic Biodiversity
Aquatic Insect Biodiversity and Conservation

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Introduction

The diversity of insects can only be described as amazing. More than half of all known species of living things (microbes, plants, and animals) are insects. There are more than 1 million known species of insects, which is about three-fourths of all species of animals on the planet. While most insects live on land, their diversity also includes many species that are aquatic. In North America, there are more than 8,600 species of insects associated with freshwater environments during some part of their lives.

Just about anywhere you go on the planet, there is some kind of insect that will live in almost any place that stays wet for a week or so. Aquatic insects are important food for fish and waterfowl. They also play important roles in keeping freshwater ecosystems functioning properly.

Not many aquatic insects have been listed as threatened or endangered, but that is only because we have only begun to study their distribution and population numbers. Many species of aquatic insects are very susceptible to pollution or alteration of their habitat. In fact, aquatic insects are the group of living things used most commonly for monitoring the health of aquatic environments.

What Are Aquatic Insects?

Insects are invertebrates (animals without a backbone) that are part of the larger group of animals called arthropods. Arthropod means "joint footed." That name was given to these animals because all of the arthropods have legs with joints that are something like our elbows and knees. Some other arthropod relatives of insects are crayfish, crabs, lobsters, millipedes, centipedes, scorpions, spiders, and ticks. Most insects are terrestrial (live on land), and are found in places such as trees, shrubs, flowers, rocks, logs, soil, buildings, and especially our gardens.

Everyone is familiar with common terrestrial insects such as butterflies, moths, beetles, ants, bees, wasps, grasshoppers, crickets, cockroaches, and flies.

There are also many kinds of insects that live in the water. These are called aquatic insects, and they are often not seen unless you explore places such as puddles, ponds, lakes, ditches, streams, and lakes. There are many different kinds of aquatic insects and almost every type of freshwater environment will have some kind of aquatic insect living in it.

Structure and appearance

Like their other arthropod relatives, insects have their skeleton on the outside of their body (exoskeleton). This outside skeleton is thick, and often hard, so that it can protect the insect, much like our skin protects us. However, an insect's exoskeleton does not grow along with the insect. As an insect grows it must shed its skin and grow a new one in order to get larger.

There are several features of insects' bodies that make them different from the other arthropods. The body of an insect is made up of three sections. The head is at the front end of the body. The thorax is in the middle of the body and is usually larger than the head. The abdomen is the rear section of the body and is usually as long, or longer, than the head and thorax together. You can usually see individual segments (up to 10) in the abdomen, but the individual segments in the head and thorax are usually fused together and cannot be easily distinguished.

The head contains structures for eating and sensing the world that an insect lives in. Insects have several different mouthparts that are specialized for tasting, obtaining, and breaking up food. There are two antennae (feelers) on the head, one on each side. There are usually two large compound eyes, which contain thousands of small individual eye cells.

The thorax contains the structures that insects use to move around. There are six legs, arranged with three on each side of the body. Some of the legs may be constructed for special movements or purposes, such as running, jumping, digging, or catching food. Most insects have four wings on the thorax. Insects are the only arthropods that can fly, which is the main reason they are more widespread and more diverse than any of the other arthropods.

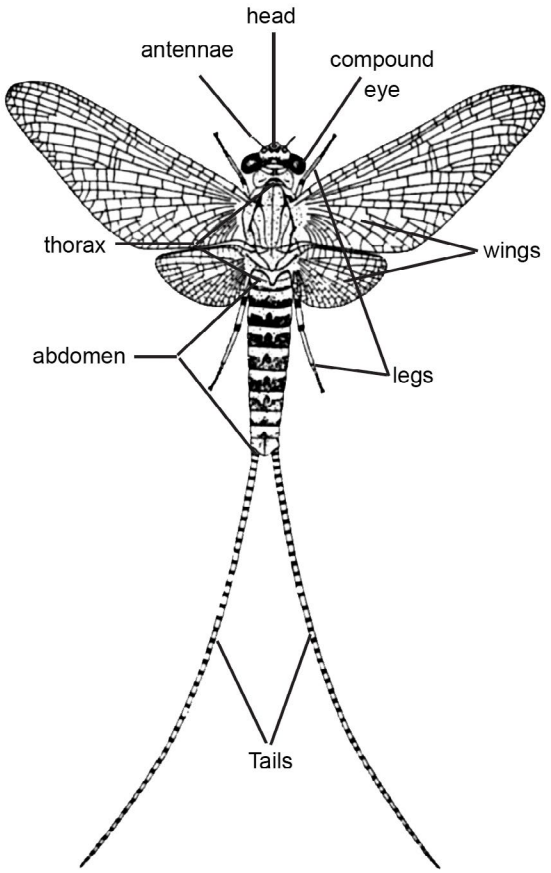


Figure 1. Major morphological features of an adult mayfly.

The abdomen does not have many structures on the outside, except for some structures at the end that are specialized for mating and laying eggs. Many insects have two tails on the rear of the abdomen, which they often use to sense vibrations.

The distinguishing features described above apply to adult insects. For many aquatic insects, only the immature stages (babies) live in the water. Sometimes the immature stages do not have the same features as adult insects. Immature insects never have working wings, and some may not have compound eyes, jointed legs, or a distinguishable thorax section. Some immature insects look more like worms than insects. However, wormlike immature insects will always have an obvious head, or at least some noticeable structures sticking out from the head, such as mouthparts or antennae, while worms never have a head or head structures.

How do they breathe?

Insects that live on land breathe air through holes in their bodies called spiracles. This would not work very well for insects that live in the water, so aquatic insects have special adaptations for breathing in the water without drowning. The most common way for aquatic insects to breathe effectively underwater is to use oxygen that is dissolved in the water rather than oxygen that is a gas in the air. Many aquatic insects, especially during their immature stages, have gills similar to fish for obtaining dissolved oxygen. The gills of aquatic insects are located on the outside of their body in various locations. Gills come in various shapes, but many are flat oval plates or tufts of small filaments. Other aquatic insects have a soft flexible external skeleton that simply allows dissolved oxygen to pass from the water into their body all over their body surface.

Some kinds still use the holes in their bodies to get oxygen from the air. They just keep the holes shut while they are underwater, and only open them when they come to the surface to take in a breath of air. Some kinds take a bubble of air underwater and breathe out of the bubble, which allows them to stay underwater longer. This is comparable to SCUBA diving. A few kinds of aquatic insects have their spiracles on the end of a long tube at the end of their abdomen. They keep their body underwater and just stick their breathing tube up to the surface to get air, much like snorkeling.

What do they eat?

The foods of aquatic insects are just as diverse as the habitats in which they live. Although individual kinds of aquatic insects may only eat one type of food, all organic material in the water, living and dead, is eaten by some kind of aquatic insect. Scientists have found it informative to categorize aquatic insects according to how they obtain their food for studying the ecology of freshwater ecosystems. These categories are called functional feeding groups.

Scrapers have special mouthparts that remove algae growing on the surface of rocks or other solid objects. These mouthparts work like a sharp blade to remove the outermost layer of algae, which is attached very tightly but is very nutritious for those insects equipped to remove it.

Collectors acquire small pieces of decaying plant material (detritus). Some kinds use long hairs on their head or legs or silk nets to filter these small particles out of the water. Other kinds of collectors use their mouthparts to gather fine particles lying on the bottom and shove this material into their mouths.

Shredders have mouthparts that are designed to nibble off pieces of soft vegetation, such as leaves, flowers, or twigs, and grind up this material. Most aquatic insects shred pieces of vegetation that have dropped off of plants and are decaying. Most of this material comes from trees and shrubs that grow on land at the edge of the water. Only a few kinds of aquatic insects feed on parts of live plants that grow under the water.

Predators feed on other animals that are alive. Predators often have special structures for catching and subduing their prey, such as strong jaws with teeth, a sharp beak, or spiny legs. Predators eat other invertebrates most of the time, but some are large and strong enough to catch small vertebrates, such as fish and tadpoles.

How do they grow?

Insects, like all arthropods, must shed their protective external skeleton periodically in order to get larger. Before they shed their old skin, they grow a new one underneath. The new larger skin is soft and folded, so that it can fit inside the old smaller skin. They also absorb much of the old skin and recycle the materials it contained. To shed the old skin, aquatic insects gulp water to make themselves larger, and they push from the inside on the top of the thorax. The old exoskeleton is thinner there, so it splits and allows the insect to climb out. After getting out of the old skin, the insect continues to gulp water to make itself larger by stretching out the wrinkles in the new soft skin. After a few hours, or in some cases a few days, the new skin hardens into another protective exoskeleton. Different kinds of aquatic insects shed their skin anywhere from three to 45 times. This is a dangerous time in the life of an aquatic insect, and many of them die while they are waiting for their new skin to harden. The new soft exoskeleton is subject to damage, and it does not allow the insect to move and hide very well.

As insects grow from eggs into adults, they go through a series of developmental changes that are called metamorphoses. There are two basic types of metamorphosis in aquatic insects. It is important to know about these two types because metamorphosis is used to help identify immature insects and it explains a lot of the biological activities in which they engage during their lives.

One type of metamorphosis is incomplete (also called hemimetabolous). Aquatic insects with incomplete metamorphosis emerge from the egg looking a lot like miniature versions of the adults, minus wings. They have compound eyes on the head and jointed legs on the thorax. The wings develop in projections on the thorax (wing pads) and get a little larger each time the insect sheds its skin. Immature stages of aquatic insects with incomplete metamorphosis may be referred to as larvae, nymphs, or naiads.

The other type of metamorphosis is complete (also called holometabolous). Immature aquatic insects with complete metamorphosis do not look anything like the adults they turn into. At most they have only a simple eyespot or a small cluster of eyespots on the head, and some have no eyes at all. They may or may not have jointed legs on the thorax. The wings develop inside the body, so no wing pads are visible until just before the insect becomes an adult. Insects with complete metamorphosis go into an inactive stage before they become adults. During the inactive stage is when compound eyes, jointed legs, and wing pads first show up. The active immature stages are called larvae, and the inactive stage is called a pupa. Some aquatic insects crawl out of the water for the pupal stage, while others spend this stage in the water.

How do they reproduce?

Only adult insects are capable of reproducing, and most aquatic insects spend their adult stage out of the water. After mating on land, females return to the water to deposity their eggs. Eggs are usually stuck on solid objects under water, but a few kinds deposit the eggs on trees or rocks above the water. Eggs usually hatch within a few days or weeks, but some may be programmed not to hatch for many months. A delay in hatching allows an aquatic insect to live in habitats that are too hot, are too cold, or dry up during part of the year.

Different kinds of aquatic insects require anywhere from a few weeks to several years to develop into adults. Most grow and develop steadily, but some may go into an inactive state to endure harsh environmental conditions. It is most common for aquatic insects to produce one generation per year, with the adults emerging during the warm months. Some of the larger kinds, or those living in cold environments, require two to three years to develop from egg to adult. Some kinds with short developmental times may produce more than one generation per year. In southern latitudes of the United States, some kinds reproduce continuously throughout the year.

Adult aquatic insects usually live a few days to a few weeks. The extremes of adult life span range from a few minutes (some mayflies) to two or three years (some water beetles).

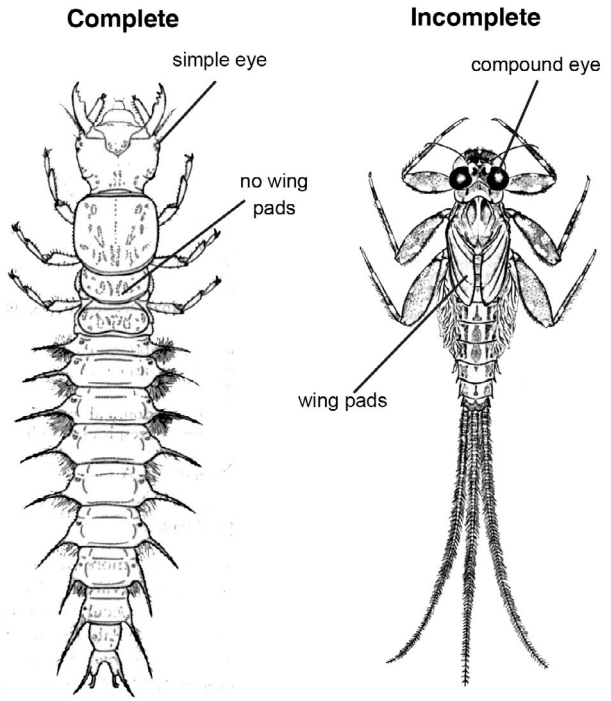


Figure 2. Two types of metamorphosis. Megalopteran larva (left) and mayfly nymph (right).

Where Do They Live?

One of the most amazing things about aquatic insects is the diversity of habitats where they live. There is no body of water that is too small, too large, too cold, too hot, too muddy, with oxygen too low, with currents too fast, or even with too much pollution for some kind of aquatic insect to live there. About the only restriction to where they live is that they do not usually inhabit the salty water of marine environments, such as oceans and bays. However, there are even a couple of unusual aquatic insects that live on coral reefs and in tide pools of marine environments. Estuaries, where the fresh water of rivers mixes with the salt water of oceans, are home to quite a few kinds of aquatic insects. Anyone who has been to the beach knows about the kinds of mosquitoes that breed in the salt marshes near the beach.

Not all kinds of aquatic insects live in all types of freshwater habitats. The most favorable habitats, and the ones where you can collect the most kinds of aquatic insects, are the edges of ponds and lakes and the sections of streams and rivers where the water is flowing fast enough to splash (riffles). In both standing and flowing freshwater habitats, the most different kinds of aquatic insects will be found in water that is less than three feet deep and can be easily waded.

Aquatic insects have a variety of special adaptations for moving around or staying in one place within their habitat. Some are agile swimmers by means of streamlined bodies with long legs or tails, while others climb around on aquatic plants by means of long thin bodies. Some sprawl on top of soft mucky bottom without sinking in because their bodies are flat and their legs extend out from the sides. Others are able to burrow down into soft mucky bottom because they have special structures on their bodies, such as legs that look like shovels or points projecting in front of their heads. Still others can cling to rocks and logs in very swift current because their bodies are very flat and the current just passes over them without knocking them off. Other clingers stay put by using special suckers or by gluing themselves down with sticky silk that they produce. Lastly, many aquatic insects like to crawl around in the tiny spaces among rocks, sticks, and dead leaves.

Because aquatic insects are small and highly specialized, different kinds are often found in small areas with similar features, which are called microhabitats. Examples of microhabitats where you will probably find different aquatic insects are: cobble rocks (about the size of your fist or head), gravel, sand, muck, accumulations of dead leaves and twigs, live plants, and grasses and tree roots that extend into the water from land. Different microhabitats, with different aquatic insects living in them, occur very close together, perhaps within one step of each other.

Aquatic insects even live in temporary habitats, such as small streams or ponds that dry up in the summer. If they are adults, they can simply fly to another place with water. Some immature aquatic insects that cannot yet fly will burrow down into the bottom where it is damp and go into an inactive state, something like animals hibernating over winter. However, most aquatic insects that live in temporary habitats are "programmed" to stay in their eggs, where they are protected, until the time of year when water is present.

Observing Aquatic Insects

Aquatic insects are always easy to collect for observation because they are so numerous and they live in so many different places. The simplest way is just to pick up objects in the water, such as rocks, plants, sticks, or leaves, and examine the material. Sometimes it works best to place the object in a shallow pan with

clean water. You can see aquatic insects with your naked eye, but a magnifying glass might help to find some of the smaller ones.

You will probably collect more organisms by using a net with fairly fine mesh. These are available in stores or you can build your own from materials around the house. If there is a current, hold the net in the water downstream of where you think aquatic insects might be living. Gently shake or move the habitat where the insects may be. It works best if you move the habitat with your hands, but it will also work to kick with your feet (it just damages more of the organisms). Either way, aquatic insects and some of the material where they were living will wash right into your net. If you are in standing water, you will need to move the net in the places where the aquatic insects live. Usually short pokes with the net work best. After collecting material in the net, empty the contents into a shallow pan with clean water to find the aquatic insects.

There is no reason to kill aquatic insects unnecessarily, so it is always best to release them back into the water alive after studying them for a while. If you need to preserve aquatic insects for a specific purpose, the best method is to place them in alcohol in a small clear container with a tight-fitting lid. Rubbing alcohol (isopropanol) works fine. You should put a paper label in the container stating what kind of aquatic insect it is, as well as where and when you collected the organism. The labels should be written in pencil or indelible ink.

Federal and state laws govern when, where, and what wildlife may be collected. Regulations may differ between collecting for personal use, educational purposes, and scientific research. Be sure to adhere to all laws and regulations regarding wildlife collection and habitat disturbance.

What Good Are They?

Aquatic insects are probably best known for their ability to tell us about the water quality in a particular environment. Some of them are very sensitive to pollution, while others are tolerant. If you take a sample of the aquatic insects in a particular place and analyze the sample in terms of the sensitive kinds versus tolerant kinds, you can get a good measure of the environmental health. Healthy aquatic environments have a lot of different sensitive kinds, while polluted environments have only a few kinds of tolerant aquatic insects. This process is called biological monitoring (or biomonitoring) and is commonly done by government agencies as well as citizen volunteer organizations.

However, the use of aquatic insects for biomonitoring is not the main reason that they are important. Because there are so many different kinds of aquatic insects and their activities are so diverse, they perform essential roles that keep freshwater ecosystems functioning properly. A good analogy would be the various jobs of factory workers on an assembly line that are necessary to make sure that a manufacturing plant turns out plenty of good products.

Some of the aquatic insects are responsible for breaking down the dead leaves and other plant parts that fall into bodies of water from land. This material provides the base of the food chain in some aquatic environments, especially small streams in forests.

Some scrape the algae that grow on all firm surfaces in water, such as rocks, logs, and the leaves and stems of live rooted plants. This layer of algae, which produces much oxygen and food for other organisms, is more productive if it is kept thin by the grazing of aquatic insects and other invertebrates.

Other kinds of aquatic insects are specialized for filtering fine particles that are suspended in the water. This is useful because it helps to keep the water clear enough for light to penetrate where algae and other plants are growing on the bottom.

Other kinds mix the soft bottom sediments as they burrow in search of food. This makes the bottom healthier for organisms because it puts oxygen from the water into the bottom.

Lastly, the aquatic insects that are predators reduce the numbers of other invertebrates and help keep a balance among the different kinds of organisms and the food that is available.

Even if aquatic insects did not perform these important jobs in aquatic ecosystems, they would still be useful just because collecting and observing them is so easy and so much fun. Aquatic insects are an excellent way to get people of all ages interested in nature and conservation of natural resources.

Aquatic Insect Killers: Threats

Hardly any species of aquatic insects have been listed as endangered or threatened. However, the reason for this is that studying the distribution and population numbers of such a diverse group of organisms is an overwhelming task. Also, most people do not understand and appreciate the importance of these small creatures in freshwater ecosystems. It is certain that many species of aquatic insects are threatened and perhaps on the verge of extinction. These are most likely to be species that have narrow ecological requirements, and, thus, live in unique habitats that have not been disturbed by human activities.

In the past, aquatic insects were severely reduced in many bodies of water by discharges of toxic substances, such as those from manufacturing plants and mines. Also, overloaded sewage treatment plants discharged human waste, which used up all of the dissolved oxygen when it decayed. Today in the United States, most of those point source discharges have been greatly reduced by strict enforcement of anti-pollution laws.

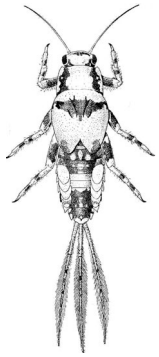
However, aquatic insects still face a great threat from nonpoint source pollution. This widespread problem comes mainly from excessive amounts of nutrients and sediment that get into streams, rivers, ponds, and lakes from so many different sources that it is hard to track them all down. Human activities that contribute most to nonpoint source pollution are agriculture and urban development. Many kinds of aquatic insects are eliminated because the excess nutrients and sediment cover the surfaces where aquatic insects need to hold on or clog the small spaces where they need to hide. In addition, these pollutants cause the water to have less dissolved oxygen. Other current nonpoint source problems for aquatic insects include warm water temperature caused by removing the trees that grow along streams and the introduction of toxic substances that wash off of city streets and people's lawns.

Major Groups of Aquatic Insects

There are so many different kinds of aquatic insects, it is difficult to appreciate their biological diversity without considering some of the individual kinds. The following section provides a brief summary of the eight major groups.

Mayflies (Ephemeroptera)

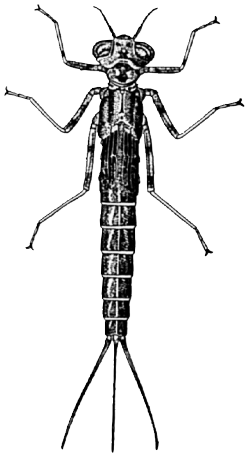
Larvae of mayflies live in a widevariety of flowing and standing waters. Most of them eat plant material, either by scraping algae or collecting small pieces of detritus from the bottom. Larvae breathe dissolved oxygen by means of gills on the abdomen. They have incomplete metamorphosis. Most mayflies are sensitive to pollution, although there are a couple of exceptions. The most unusual feature of mayflies is that the adults only live a few hours and never eat.



Mayfly nymph

Dragonflies and Damselflies (Odonata)

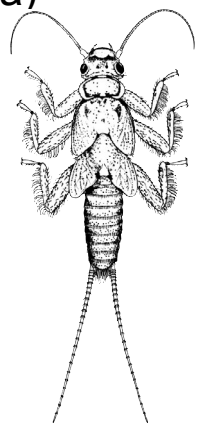
Larvae of dragonflies and damselflies are most common in standing or slow-moving waters. All of them are predators. Larvae breathe dissolved oxygen with gills, which are located either inside the rear portion of the abdomen (dragonflies) or on the end of the abdomen (damselflies). They have incomplete metamorphosis. Many kinds are fairly tolerant of pollution, but some kinds only live in unique habitats, such as bogs high in the mountains. The most unusual feature of this group is the way the larvae catch their food with an elbowed lower lip, which they can shoot out in front of the head.



Damselfly nymph

Stoneflies (Plecoptera)

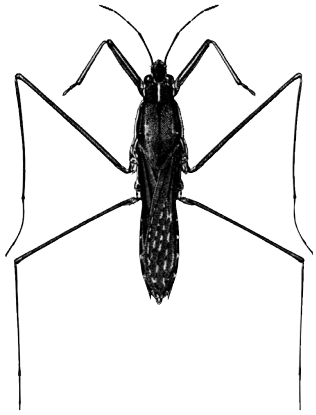
Larvae of stoneflies live only in flowing waters, often cool, swift streams with high dissolved oxygen. Some feed on plant material, either by shredding dead leaves and other large pieces of detritus, while others are predators. Larvae breathe dissolved oxygen. Some have gills on their thorax, but others just obtain dissolved oxygen all over their body. They have incomplete metamorphosis. Almost all of the stoneflies are



Stonefly nymph

sensitive to pollution. The most unusual feature of this group is that some kinds are programmed to emerge only during the coldest months; hence, they are called the winter stoneflies.

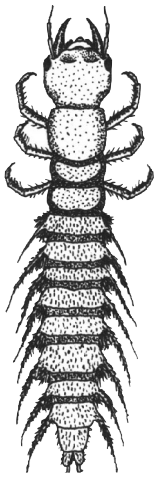
True Bugs (Hemiptera)



Adult stage of a water strider, a Hemipteran larva

Most of the true bugs live on land, but the aquatic kinds are most common in the shallow areas around the edge of standing waters. Both the adults and the larvae of the aquatic kinds live in the water. Both stages are usually found on submerged aquatic plants. Almost all of them are predators. They breathe oxygen from the air, either by taking a bubble underwater or by sticking a breathing tube up into the air. They have incomplete metamorphosis. Most kinds are tolerant of pollution. The most unusual feature of this group is the way they kill and eat their prey. True bugs have a sharp beak that they stick into the body of their prey, and then they pump in enzymes to kill their prey, after which they suck out the body fluids. Some of the larger kinds feed on small fish and tadpoles.

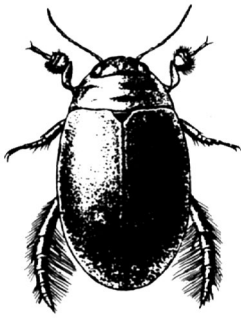
Dobsonflies and Alderflies (Megaloptera)



Megalopteran larva

Larvae of different kinds of dobsonflies and alderflies live in flowing or standing waters. They are all predators. Most breathe dissolved oxygen by means of gills and their overall body surface. They have complete metamorphosis. Mature larvae leave the water and dig out a protected space under a rock or log for the pupa stage. Various species are either sensitive or tolerant to pollution. Larvae of some of the larger kinds are called hellgrammites, which are popular as live bait for smallmouth bass and other warm-water fish species.

Water Beetles (Coleoptera)



Adult stage of a water beetle

There are more known species of beetles than any other insects, but most of them live on land. Most of the water beetles are more common in standing or slow-moving waters, but a few kinds are only found in swiftly flowing waters. Both the adults and the larvae of the aquatic kinds live in the water. Water beetles feed in different ways, primarily by preying on other animals, scraping algae, or collecting small particles of detritus from the bottom. All of the adults breathe air by taking a bubble underwater, while most of the larvae breathe dissolved oxygen by a combination of gills and their overall body surface. They have complete metamorphosis and leave the water for the pupa stage. Water beetles range from sensitive to somewhat tolerant of pollution. The most unusual feature of water beetles is that some of the adults live for several years.

Caddisflies (Trichoptera)

Caddisfly larva

Larvae of different caddisflies live in a wide variety of flowing and standing waters. They also have a wide range of feeding habits, including scraping algae, collecting fine particles of detritus from the bottom or from the water, shredding dead leaves, and preying on other invertebrates. They breathe dissolved oxygen by means of gills and their overall body surface. Caddisflies have complete metamorphosis and remain in the water for the pupal stage. Most kinds are sensitive to pollution, but a few kinds are somewhat tolerant of moderate levels of pollution. The most distinctive feature of caddisflies is their ability to spin silk out of their lower lip. They use this material to glue together stones or pieces of vegetation into a small house for their protection during the larva and pupa stages. Some also use strands of silk to make a net for filtering particles of food from the water.

True Flies (Diptera)

Crane fly larva (Diptera)

While most flies are terrestrial, there are still many with aquatic life stages. They have a wide range of feeding habits, including scraping algae, collecting fine particles of detritus from the bottom or from the water, shredding dead leaves, and preying on other invertebrates. They breathe dissolved oxygen by means of gills and their overall body surface. True flies have complete metamorphosis and remain in the water for the pupal stage. The most distinctive feature of this group is their ecological diversity. Some kinds live in the cleanest habitats (e.g., swift, cool, mountain streams), while others live in some of the harshest natural habitats on the earth (e.g., arctic tundra ponds, geothermal springs, alkaline lakes, mucky swamps). They have equally diverse responses to pollution, with some kinds being exceptionally sensitive, while other kinds endure the worst imaginable water quality (e.g., raw sewage or acid mine drainage).

Aquatic Insect Web Links

Aquatic insects are widely studied at all levels by educational institutions, government agencies, and citizen volunteers who monitor water quality. Using terms such as aquatic insects, freshwater invertebrates, or benthic macroinvertebrates with your favorite web search engine will locate many informative sites. Here are just a few examples.

The Atlas of Common Freshwater Macroinvertebrates of Eastern North America: https://www.macroinvertebrates.org.

Virginia Save Our Streams Macroinvertebrate ID resources: https://vasos.org/monitor-page/stream-insect-id-resources/

http://lifeinfreshwater.net/

Suggested Reading

Voshell, J.R., Jr. 2002. *A Guide to Common Freshwater Invertebrates of North America.* McDonald & Woodward Publishing Company, Granville, Ohio. 442pp.

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